Estimation and Visualization of Seafloor Uncertainty

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LONG-TERM GOALS

The long-term goal of the Capturing Uncertainty DRI is to assess and characterize uncertainty in the tactical naval environment. As part of the Seafloor Variability team, the focus of our effort is to develop approaches to characterize uncertainty associated with measurements of bathymetry and other seafloor properties that are important for sonar performance predictions. We are also developing innovative methods to visualize this uncertainty.

OBJECTIVES

The scientific objectives of the UNH team are:
1. Develop methods to characterize uncertainty in bathymetry from modern Multibeam Echosounder (MBES) systems. This provides information that is essential in understanding our knowledge of a fundamental driver of sonar performance.
2. Develop methods to characterize and estimate uncertainty in historical bathymetric datasets, and in the combination of historical bathymetric datasets to form compilations.
3. Develop and deploy techniques to accurately measure, *in situ*, key physical and acoustical properties of seafloor sediments in selective shelf environments so that we may have real estimates of the spatial scales of variability of these parameters (shared with Geoclutter and Mine Burial DRIs).
4. Develop sophisticated 3-D visualization techniques that can convey the captured uncertainty in a useful and intuitive manner.

APPROACH

The research described here is part of a larger effort to understand the seafloor's influence on the uncertainty associated with sonar performance. The outputs of our work are direct inputs to the uncertainty propagation process, since they do not depend on other measurements or properties of the acoustic system. The wider effort is described in Holland's Team Leader report.

Quantification of uncertainty in bathymetric datasets: Bathymetry is a primary driver of acoustic propagation and hence of sonar performance. It also forms a fundamental input into propagation modeling and performance prediction. Typically, echosounder measurements of bathymetry are

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regarded as 'ideal' in the sense that every measurement not obviously wrong is considered to be as good as all of the others. Our approach has been to estimate the uncertainty associated with each sounding, based on a reasonable model of echosounder performance, and then utilize these measurements to inform and control the estimation of bathymetry and its associated uncertainty. The approach is embodied in the CUBE (Combined Uncertainty and Bathymetry Estimator) algorithm, as described in [1, 2].

Assessing the uncertainty of historical datasets provides a formidable task. Our work has used Monte Carlo methods [3] to estimate uncertainty in compilation datasets in the face of uncertain source data. However, this method assumes that we have some *a priori* information on performance of the echosounders in question. We consider the case where we have measurements of a particular location from the target sensor, and repeated measurements using a much more accurate sensor. We use the depth predictions from the modern survey (where the accuracy is given) to estimate the uncertainty associated with the target sensor. If we assume that surveys carried out with the same types of sensor at about the same period are statistically similar, this process can be used to calibrate the target sensor more generally, providing a sound footing for our other analysis methods.

Our estimates of bathymetry are necessarily affected by uncertainty in the oceanography of the survey region. In particular, the uncertainty in spatio-temporal variation of sound speed profile is potentially a major driver of error and uncertainty in echosounder performance (particularly of MBES systems). We hypothesize the use of an ocean model to provide predictive capacity, generating 'model' sound speed profiles at the appropriate time and location so as to minimize any uncertainty in prediction of appropriate oceanographic properties. We will be testing this hypothesis through experimental data gathered during the HFX experiment (Kaua'i, Hawai'i, June 2003).

In situ **measurement of seafloor acoustic properties:** In support of another ONR DRI (Geoclutter), we have developed, built, and deployed a relatively inexpensive, robust, ship-deployable device (**ISSAP** – *In situ* **S**ound **S**peed and **A**ttenuation **P**robe) for making very accurate measurements of sound speed, attenuation, and porosity in surficial sediments [4]. The ISSAP uses four 30 cm long probes (2.54 cm in diameter) that are inserted into the seafloor under 250 kg of reaction weight attached by armored coaxial cable to a free-swinging inner frame within a protective outer tripod. There are two sets of probes with nominal operational frequencies of 65 and 100 kHz. A Labview program and console electronics control the path selection, number of transmitted pulses, and trigger rate. A typical deployment involves 'time-of-flight' measurements across five paths including both long (30 cm) and short (20 cm) paths. In addition to the acoustic probes, ISSAP also has a color video camera providing imagery of the seafloor and insertion of the acoustic probes as they penetrate the seafloor, an altimeter to independently monitor the platform height above the seafloor, an instrument to measure platform attitude, temperature and pressure, and resistivity probes to measure *in situ* porosity. ISSAP makes multiple measurements of *in-situ* properties by simply 'pogo-ing' on the seafloor and is able cover a relatively large area of the seafloor in a short period of time. This device has been deployed in the Geoclutter field area and the Martha's Vineyard Mine Burial experiment area and directly addresses the question of the spatial variability of key geoacoustic sediment properties.

Visualization of uncertainty: We continue to explore modes of visualizing this uncertainty (both 2 and 3-D) within the context of the geospatial information, striving to find the optimal way of presenting key information to the user in the most intuitive manner possible. In the course of this work we will take advantage of the developments of the UNH Data Visualization Lab combining modern high-end, low-cost, graphics boards with a sophisticated interactive 3-D environment that allows us to

explore the use of color, shading, draping, transparency and perhaps even stereo or pixel motion, as means of simultaneously presenting both the underlying data and the uncertainties associated with it.

WORK COMPLETED

Quantification of uncertainty in bathymetric datasets: The CUBE algorithm has been extensively validated during the reporting period (in conjunction with colleagues in NOAA), using a number of hydrographic datasets. This validation is now complete, and CUBE is actively being transitioned into practice through a number of licensing agreements.

We have supported other members of the DRI by re-processing archive MBES data for the New Jersey STRATAFORM area in order to provide co-registered bathymetry and uncertainty estimates. This has also been used as the basis for sensor calibration experiments for historical datasets using NOAA/NOS Singlebeam Echosounder (SBES) surveys in the same area.

We have carried out an experiment in conjunction with Scientific Solutions Inc. to test the ocean model method of accounting for and assessing uncertainty in bathymetry associated with spatio-temporal variability of sound speed profiles. Data collection took place in conjunction with the HFX experiment in Kaua'i, Hawai'i in June 2003, and preliminary analysis of the data is under way.

In situ **measurement of seafloor acoustic properties:** ISSAP was deployed in the Geoclutter field area off New Jersey on the *R/V Cape Henlopen* between 30 July and 5 August 2001 and in the Mine Burial field area off Martha's Vineyard in August 2002. The ISSAP system performed flawlessly recovering water column and surficial sediment 'time-of-flight' measurements at 99 stations in the Geoclutter area and 102 stations in the Mine Burial area selected to represent a range of seafloor backscatter types. Waveform data was processed to determine compressional wave sound speed and attenuation. Resistivity-based porosity measurements were also completed in the Mine Burial area. Nearly 120000 discrete measurements have been collected amounting to more than 60 Gigabytes of data as well as more than 40 hours of video.

Visualization of uncertainty: We have explored a number of approaches to visualizing uncertainty through our work with CUBE and the historical bathymetric data model. Examples are presented in the figures below.

RESULTS

Quantification of uncertainty in bathymetric datasets: Through MBES datasets in Woods Hole, MA and Snow Passage, AK, we show [1] that CUBE estimates are equivalent to the traditional hydrographic process, given the uncertainty associated with the data and the quality of survey required. A further comparison of the Snow Passage data using human operators (in conjunction with NOAA's Pacific Hydrographic Branch) showed equivalence at the level of a nautical chart through comparison with an extant traditional product. A further experiment [5] indicates that significant speed improvements can be had using the method, on the order of 30:1 over traditional (manual) methods.

We re-processed the archive STRATAFORM high-resolution MBES dataset using CUBE (Figure 1a), and then identified archive NOAA SBES surveys in the same region (New Jersey margin) using a GIS database maintained at CCOM/JHC [6]; the singlebeam surveys are from the mid-1970s. Comparison of the SBES to the MBES allowed us to construct a calibration curve for the uncertainty of the SBES

surveys of the time (Figure 1b), which should be suitable for equivalent data of this vintage in other regions. A Monte Carlo analysis [3] of surface uncertainty from the SBES dataset given this model (Figure 2) showed that small features, and particularly slopes, in the area are poorly determined by the data, an essential piece of information for reliable and responsible use of this type of data in further processing.
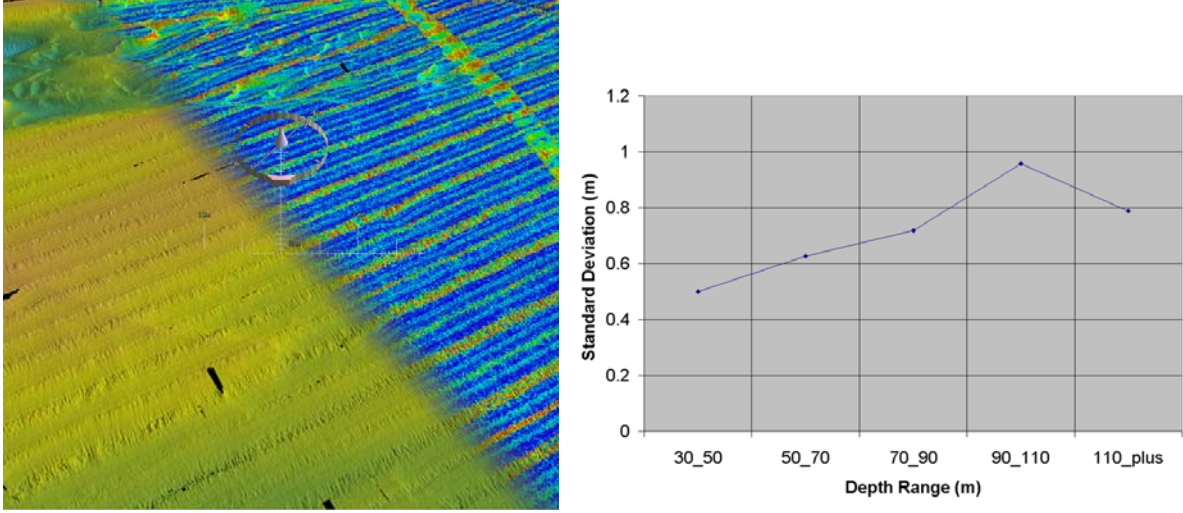

Figure 1: CUBE analysis of archive Multibeam Echosounder data (STRATAFORM, New Jersey) [left] provides ground-truth, uncertainty-quantified, bathymetry for further work. A comparison of singlebeam soundings from archive NOAA surveys in the same area (from 1975-76) to the high-resolution bathymetry allows us to construct a calibration curve for the singlebeam survey's uncertainty [right]. Since methods were typically consistent across datasets, we can also use this calibration curve to analyze uncertainty in other datasets of the same vintage and method, even in the absence of any controlling high-resolution bathymetry.
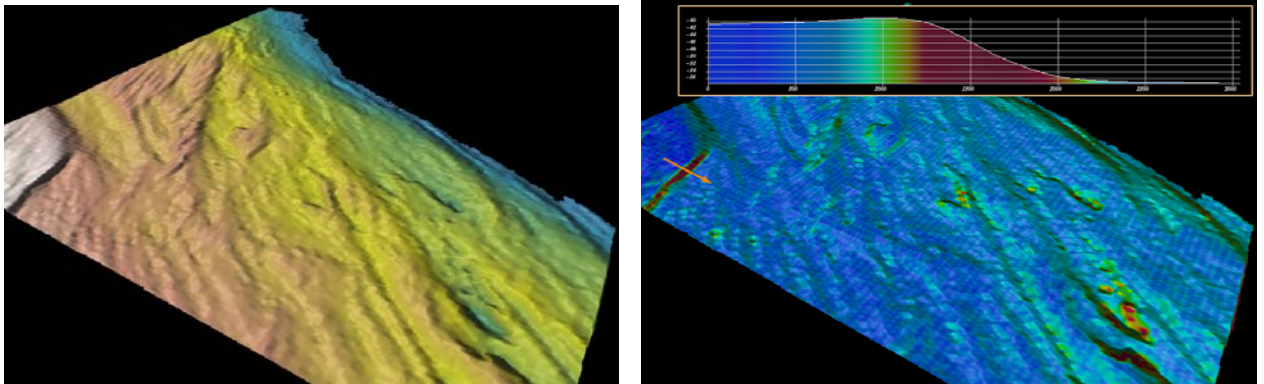

Figure 2: Reconstructions of bathymetry from low-resolution historical datasets [left] are often used without any consideration of their uncertainties. Using the method of [3] and the calibration curve of Figure 1b, we can show that the reconstruction is good in some areas, but significantly limited in others [right, color-coded uncertainty overlaid on bathymetry from left], particularly along significant bathymetric slope regions, as indicated by the profile (hotter colors indicate higher estimated reconstruction uncertainty). This is a combined error from vertical uncertainty of the data and limited accuracy in positioning due to the methods in use at the time.

***In-situ* measurement of seafloor acoustic properties:** The NJ sediments were, at a majority of stations, poorly sorted and contained a high percentage of coarse shells and cobbles. The MV sediments were generally well sorted and ranged from very fine sand to very coarse sand. Both field areas observed large scale variability in sound speed (NJ, 1524 m/s to 1801 m/s and MV, 1575 m/s and 1805 m/s) and attenuation (NJ, 10 dB/m to 71.3 dB/m and MV, 8 dB/m to 57.4 dB/m). The distribution of sound speed variability is shown in Figure 3. The range of small scale variability over spatial scales of less than a meter (station variability) is shown in Figure 4. Although most stations have a coefficient of variation in sound speed of less than 1%, the coefficient of variation is noticeably smaller for the MV stations. This is primarily due to the better sorting of the MV sediments as well as the absence of coarse material. Most of the small scale variability present in MV was confined to the transition regions where the sediment distinctly changed from very fine to coarse grained sediment.
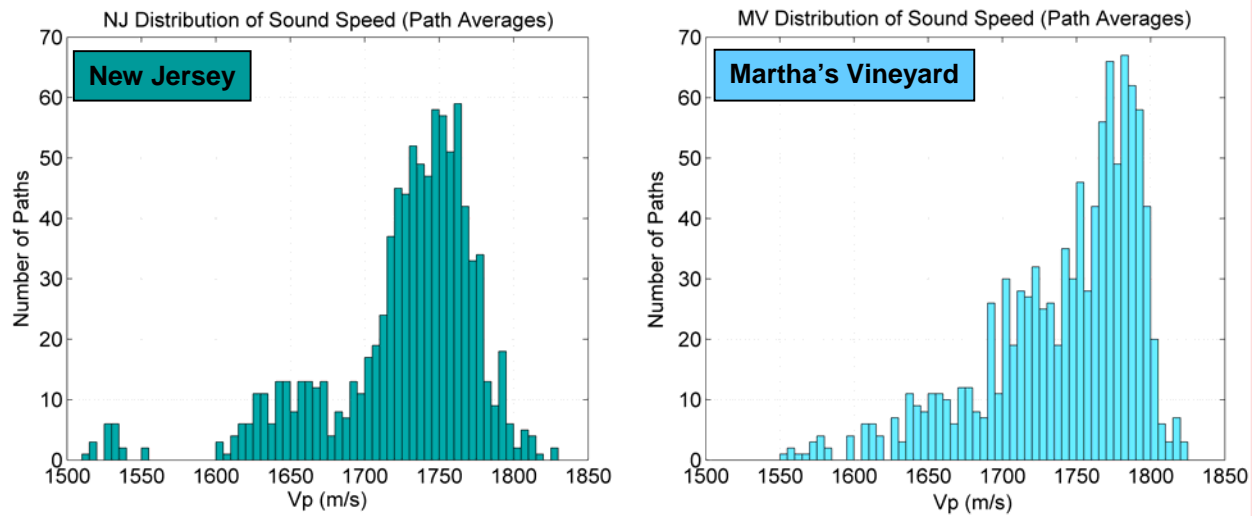

Figure 3: Distribution of measured sound speed in the Geoclutter and Mine Burial field areas. Each measurement represents a path average of approximately 60 'time-of-flight' measurements.
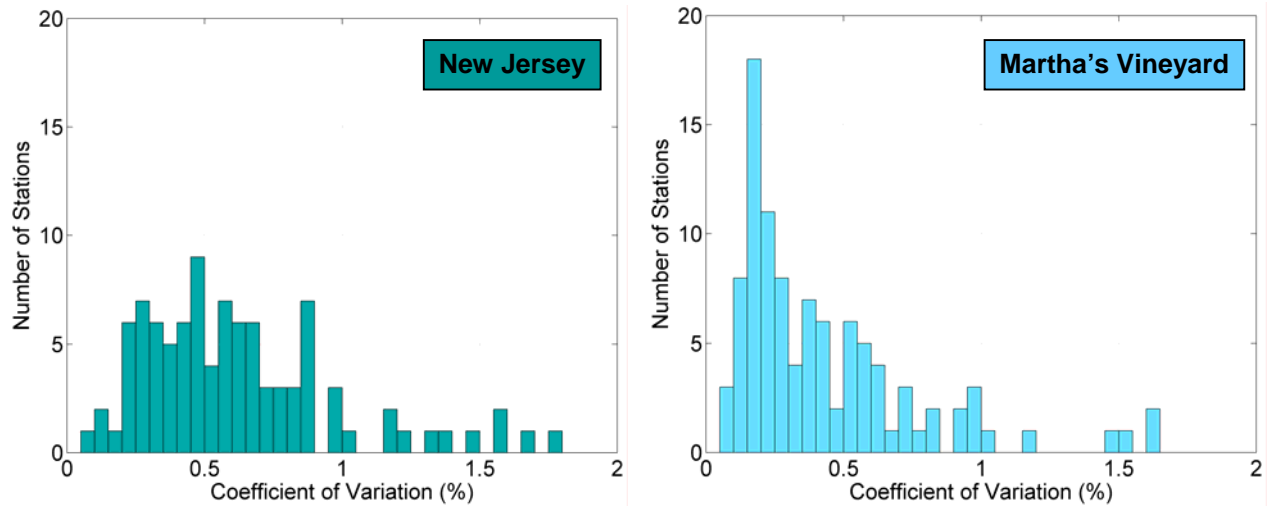

Figure 4: Distribution of the coefficient of variation of measured sound speed in the Geoclutter and Mine Burial field areas. Each measurement represents the station average of approximately 300 'time-of-flight' measurements obtained on 5 different acoustic paths.

These measurements provide the fundamental basis upon which the statistical abstractions of other team members are based. We also continue to explore the use of seafloor backscatter measurements for remotely characterizing these scales of variability.

IMPACT/APPLICATIONS

Quantification of errors in bathymetric datasets provides error limits for propagation into performance prediction and modeling software. Automatic methods for data processing based on these error estimates allow bathymetric data to be turned into information much more rapidly. Advanced visualization techniques allow us to develop methods for transmitting uncertainty information to the tactical naval situation (environment). The ability to rapidly and very accurately measure *in situ* acoustic and physical properties provides a direct measure of the spatial scales of variability in key areas and ground-truth for subsequent statistical models that may be valuable in predicting spatial scales of variability.

TRANSITIONS

CUBE has been transitioned to Interactive Visualization Systems Ltd (IVS) [7] and CARIS Ltd through license agreements. Both companies make visualization and echosounder data processing software currently in use with NOAA and NAVO. Deployment is expected during 2004.

RELATED PROJECTS

Mine Burial DRI, Geoclutter DRI, SBIR with Scientific Solutions Inc. (effects of ocean model outputs on bathymetry, and vice versa).

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